Proc. Roy. Soc. Victoria, 25 (N.S.), Pt. II., 1913.

Art. XXIV.—*The Viscosity of Cream.*

By FRANCES K. M. DUMARESQ, M.A., B.Sc.
(Physiological Laboratory, University of Melbourne).

[Read 12th December, 1912].

It seems to be commonly supposed that the thickness or viscosity of cream affords a fair test of its richness in fat; investigation, however, discloses a number of factors which affect the viscosity to a greater or less extent. Amongst these there are three to which a more prominent influence upon viscosity must be attributed—viz., acidity, fat content and temperature; but besides these there are several minor factors, which exercise an undeniable influence upon the viscosity, and whose relative importance is difficult to estimate. For instance, such factors as mechanical agitation, growth of organisms, exposure to higher or lower temperatures for a considerable period (all of which may be included under the term "previous history of the cream"), certainly have their effect upon the viscosity, but these can hardly be independently investigated, and hence their individual contribution to the general effect cannot readily be calculated. Again, the size of the fat globule may be of importance, or, since each globule may be encased in a layer of protein, the number of fat globules in a given volume of cream of known fat content may have an appreciable effect in determining the viscosity.

The nature of the protein may vary, as regard its physical condition, in creams from different sources, but it would be difficult to obtain an experimental evaluation of the viscosity effect of this factor, owing to the impossibility of ascertaining whether the various samples of cream under observation were directly comparable in other respects.

Hence in the following paper the variations in viscosity due to acidity, fat content and temperature changes are alone taken into consideration.

Acidity of Cream as Affecting Viscosity (*Critical Acidity*).—This is assuredly the most potent of the factors generally recognised as influencing viscosity. A fresh cream, of fat content as great as 40 per cent., will be comparatively liquid, and on this account ordinary commercial pasteurised cream seldom appears sufficiently rich to the average purchaser.

On the other hand, a cream of less fat content may, if acid, be apparently rich, and flow with difficulty.

In order to study the effect on viscosity of rise in acidity uncomplicated by other disturbing factors, a quantity of cream, obtained by separation from fresh milk, was gradually soured artificially, and its consequent increase in viscosity at a constant temperature experimentally determined.

In the majority of instances, the cream employed was obtained by immediately machine-separating milk fresh from one particular cow (new milk). Several experiments, however, were made with cream separated from milk as ordinarily supplied to the consumer in the city. These latter experiments are duly noted in the tables as having been made on commercial milk. The means employed to acidify the cream were as follow:—

(1) The addition to the sample of cream of minute quantities of pure lactic acid.

(2) The introduction of a small amount of a pure lactic culture to the cream, which was subsequently maintained for a prolonged period at a temperature of 32 deg. C., readings of its viscosity being taken at short intervals. The first method presents considerable difficulty, as local clotting is apt to occur upon the addition of the pure acid. Addition of dilute acid was attempted, but was abandoned owing to the diluting effect, with the consequent hydrolysis of the calcium caseinogenate of the cream.

Ultimately the following procedure was adopted:—A given quantity of cream, of previously determined fat content, was rapidly stirred with a glass rod just moistened with pure lactic acid. The additions thus effected were necessarily somewhat haphazard, and hence were subsequently estimated by titration of a sample of the acidified cream with N/10 alkali, using phenolphthalein as indicator.

The viscosity determinations were made with an Ostwald viscosimeter, surrounded by a water-jacket kept at a temperature of 25 deg. C. throughout the experiment, this temperature being the lowest that could be maintained approximately constant in the laboratory during the summer.

Preliminary experiments soon showed that, whilst up to a certain point gradual small additions of acid produce very slight increases in the viscosity, there is an acidity-value, at which the viscosity of the cream, as measured by the time interval required for the bulb of the viscosimeter to empty, rapidly rises. This acidity is approximately equivalent to that at which cream may be considered ripe for churning.

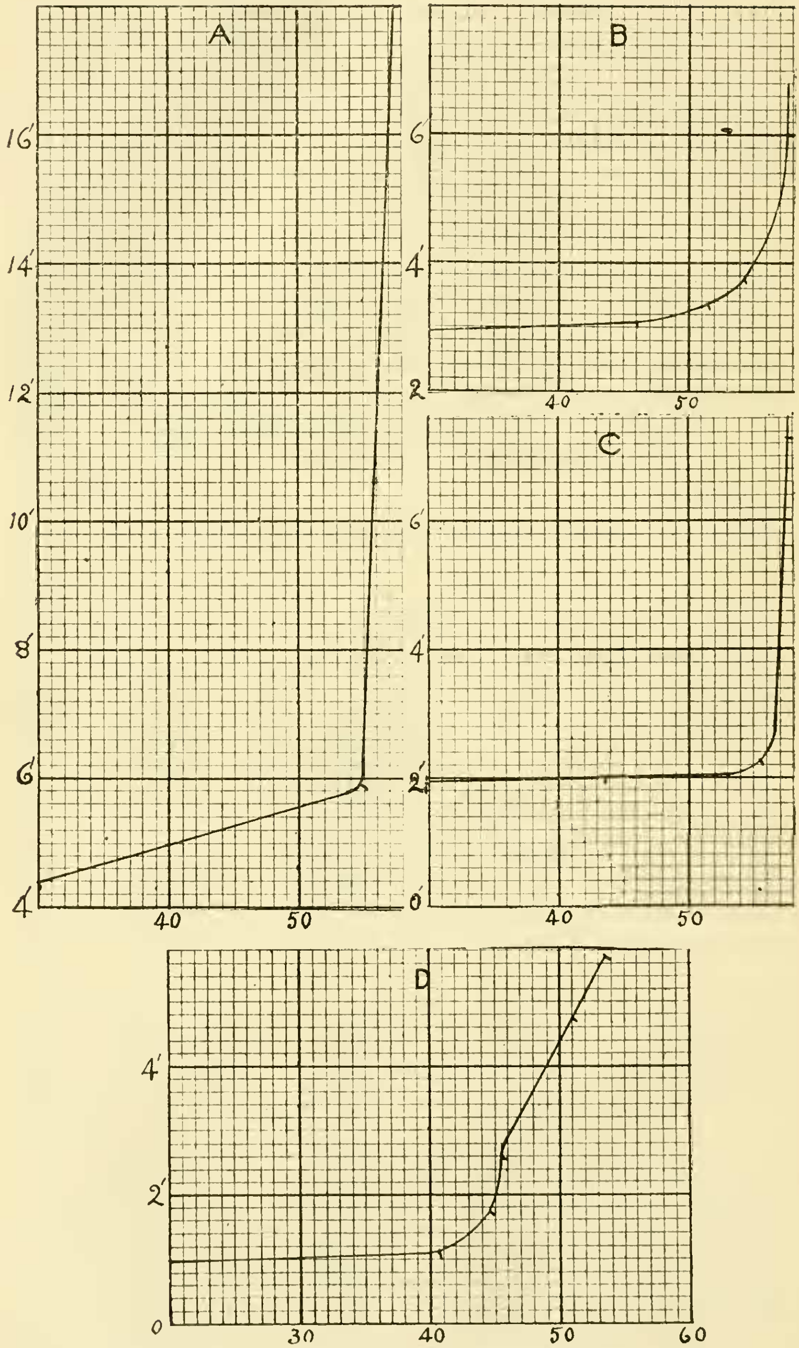
Following a suggestion made by Mr. P. Denston, dairy chemist to the Bacchus Marsh Dairy Co., it is proposed to speak of this acidity as the "critical acidity," and it can be shown that, for freshly-separated cream, the critical acidity of the cream serum is apparently a constant, independent of fat content. For example, if several samples of cream, differing in fat content be gradually acidified, there will be in each case a definite degree of acidity, at which the viscosity (which at first rises by barely perceptible amounts with small increases of acidity) suddenly increases very considerably upon the least further addition of acid. This is the critical point. The critical acidities in terms of the full cream have different values for the different samples, varying with the fat content. The fat is, however, an inert, suspended material, and if the critical acidities be recalculated for the cream minus fat—i.e., for the cream serum, they will be found to have approximately the same values.

The following experiments confirm this statement:—

TABLE I.

Cream separated from new milk, and soured by addition of pure lactic acid.

Experiment.	Time of flow. (seconds)	Acidity in cc. of $\frac{N}{10}$ NaOH per 100 cc. of cream serum.	Fat content. (per cent.)
A	240	19.6	49
	345	54.9	—
	1085	56.86	
B	170	19.67	39
	187	45.9	—
	200	51.6	—
	225	54.1	—
	360	57.2	—
C	103	15.6	36
	108	43.75	—
	136	56.25	—
	560	57.8	—
	720	68.75	—
D	57.5	17.53	23
	67	50.65	—
	105	54.54	—
	155	55.84	—
	285	61	—
	345	63.6	—



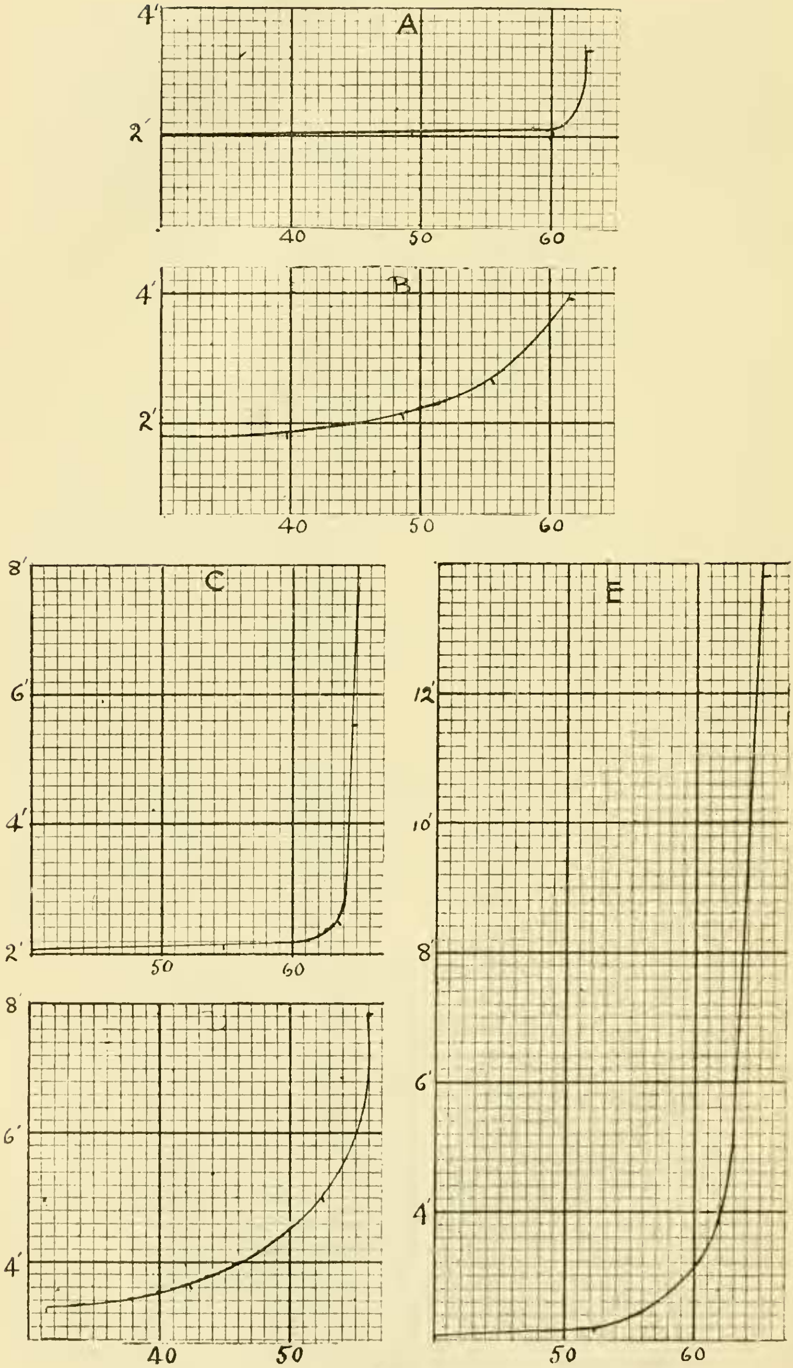
Acididity in cc. N/10 NaOH per 100 cc. cream serum.

Fig. I.

TABLE II.

Cream separated from commercial milk, and acidified by pure lactic culture.

Experiment.	Time of flow (seconds)	Acidity in cc. NaOH $\frac{N}{10}$ per 100 cc. cream serum.	Fat content. (per cent.)
A	120	22.2	37
	122	28.5	—
	126	49.2	—
	127	60	—
	201	62.5	—
B	100	15.9	32
	96	25	—
	110	39.7	—
	130	48.5	—
	160	65.9	—
	236	61.7	—
C	120	29.6	29
	130	54.9	—
	150	63.4	—
	330	64.7	—
	540	67.6	—
D	197	31.6	43
	219	42.1	—
	300	52.6	—
	450	56.1	—
E	120	21.7	—
	123	40	—
	130	52.1	—
	1080	66.6	—
F	138	33	39
	145	42	—
	150	52	—
	170	67.2	—
	3600	77	—



Acidity in cc. N/10 NaOH per 100 cc. cream serum.

Fig. II.

From these figures it appears that, for fresh cream, soured by additions of pure lactic acid, the value of the critical acidity (expressed in the number of c.c. of NaOH N/10 required to neutralise the acid contained in the cream) is between 56 and 57 cc. N/10 per 100 cc. of cream serum; but if the souring be effected by means of a pure lactic culture, the critical acidity is considerably greater, approaching 65 cc. N/10 per 100 cc. of serum, or possibly even higher.

It is, however, difficult to obtain the exact value for the critical acidity in the latter case, owing, firstly, to lack of evidence as to the probable effect of such factors as the age of the culture employed, and the rate at which it produces lactic acid in the cream, and secondly, to inability to calculate the interval of time required for the culture to bring the acidity up to the critical point, as it is found that souring produced by this means is at first slow, but at a certain stage the rate of acidification is greatly accelerated.

Effect of Previous Heating on Critical Acidity of Cream.—It is worthy of note also that previous heating of the cream may modify the results of the experiments, and give a different value for the critical acidity. Cream, which has been pasteurised after separation from fresh milk, if acidified with pure lactic acid, has a critical acidity slightly higher than fresh cream so treated.

But if the pasteurised cream is soured by introduction of a pure lactic culture, the viscosity rises gradually with increase of acidity, so that instead of a sudden rapid rise at the critical point, there is a steady increase of viscosity with increased acidity over a certain range, a pronounced rise of viscosity being attained at the degree of acidity which corresponds to the critical acidity in the cases previously described.

A few experiments made with cream from milk kept at a high temperature for some little time are interesting in that they show a difference in the behaviour of the cream so obtained, on the addition of acid.

The fresh milk was gradually heated under pressure in an autoclave until the indicator registered 105 deg. C. The milk was kept at this temperature for about 20 minutes, then removed from the autoclave and allowed to cool. The skin which had formed on the top of the milk was skimmed off, and the milk separated. The critical acidity of the cream thus obtained was found to be considerably lower than that of fresh cream or pasteurised cream.

When the milk, after heating, was cooled rapidly by being made to pass through a condenser, around which circulated a stream of cold water, the critical acidity of the cream separated from this milk was somewhat higher than that of the cream from the milk cooled slowly in the air.

This is possibly explained by the fact that in the former case very little skin formed on the milk during the cooling process; in the latter case the skin which was removed before separating the cream contained the larger fat globules, together with an appreciable quantity of protein.

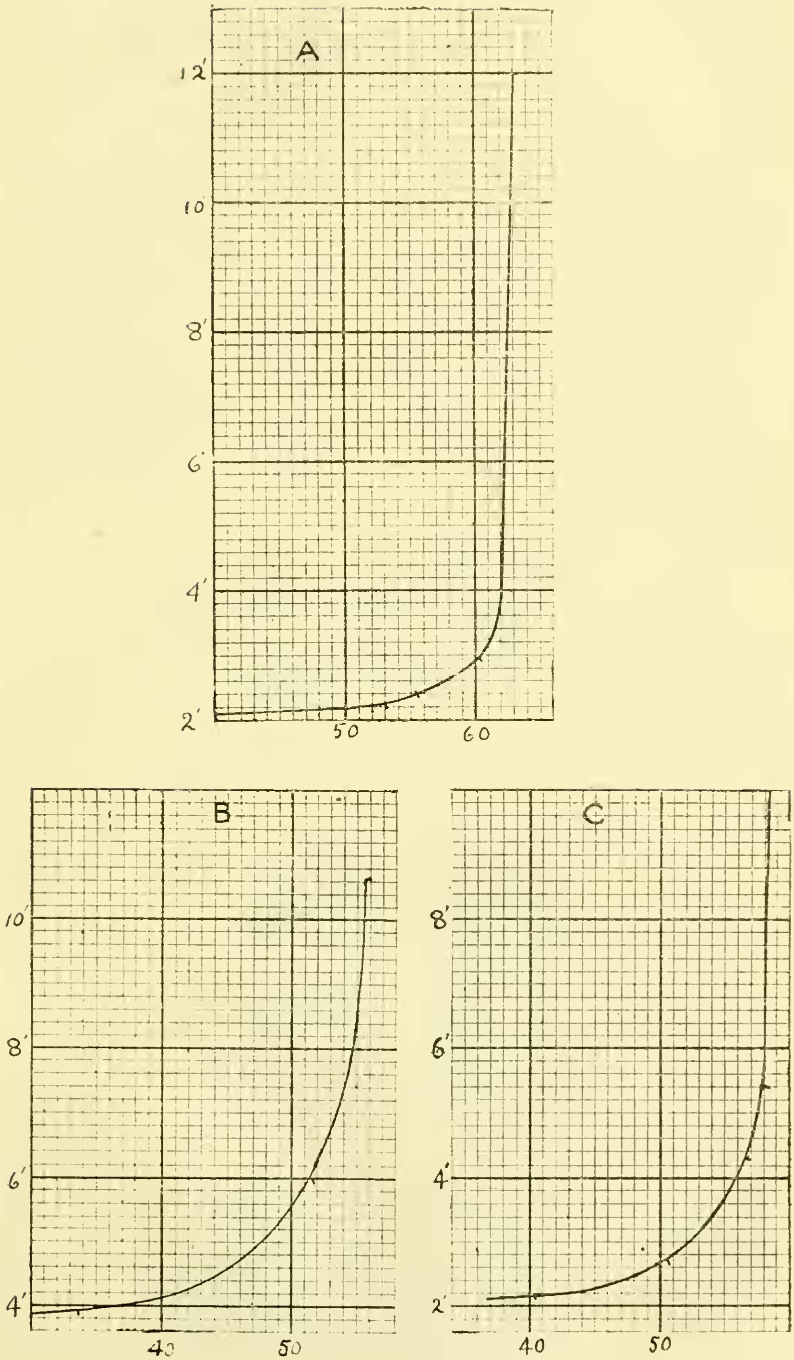
TABLE III.

Pasteurized cream from new milk soured by pure lactic acid.

Experiment.	Time of flow. (seconds)	Acidity in cc. NaOH $\frac{N}{10}$ per 100 cc. cream serum.	Fat. (per cent.)
A	118	22.2	32
	134	52.9	—
	145	55.1	—
	165	60.2	—
	1800	64.7	—

Commercial pasteurized cream acidified by pure lactic culture.

Experiment.	Time of flow. (seconds)	Acidity in cc. NaOH $\frac{N}{10}$ per 100 cc. cream serum.	Fat. (per cent.)
B	234	33.9	41
	360	51.7	—
	650	55.9	—
	1800	67.8	—
C	110	21.9	36
	130	40.6	—
	165	50.8	—
	255	53.1	—
	260	57	—
	325	57.8	—
	2700	59.4	—
	3600	68.7	—



Acidity in cc. N/10 NaOH per 100 cc. cream serum.

Fig. III.

17A

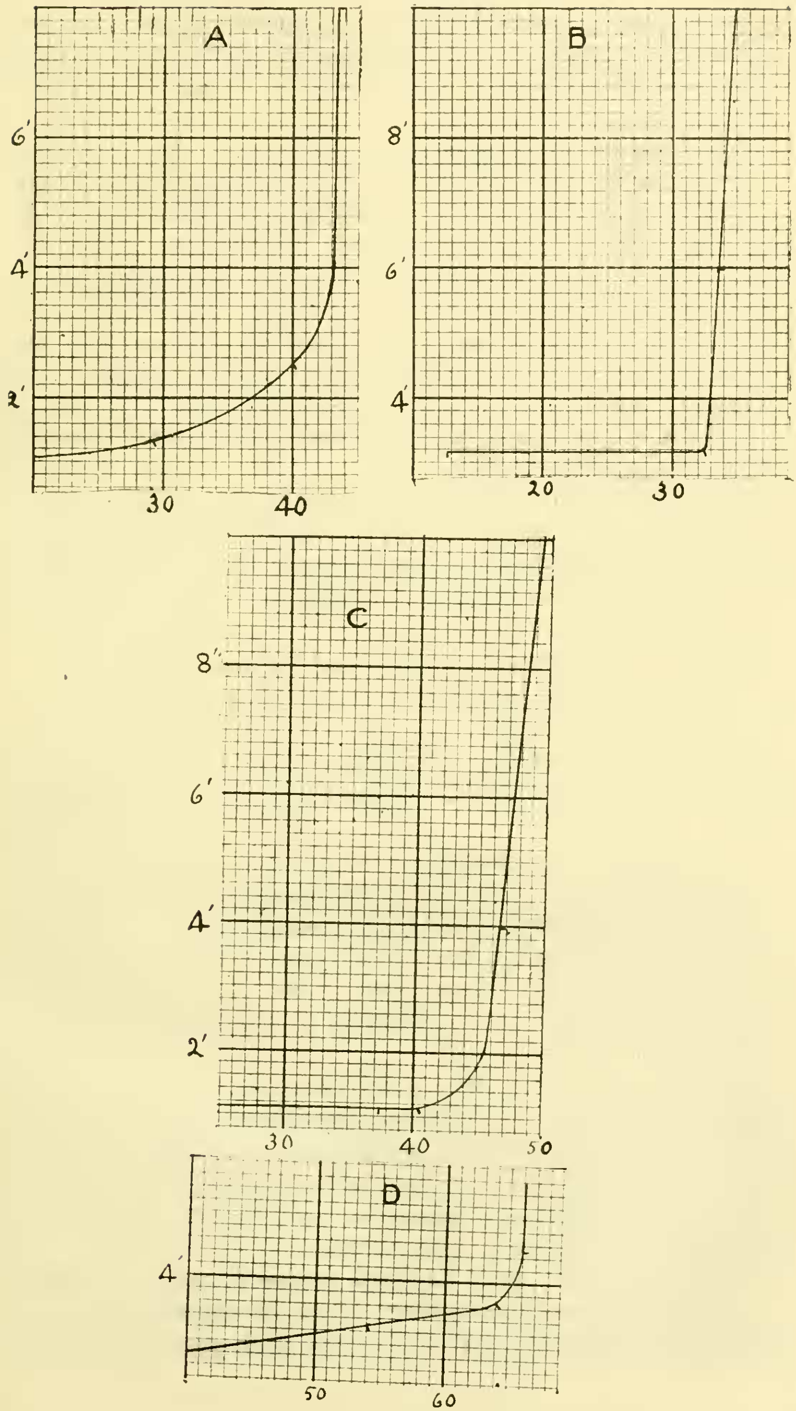
TABLE IV.

Cream from commercial milk previously heated for 20 minutes to 105° C, allowed to cool slowly.

Experiment.	Time of flow. (seconds)	Acidity in cc. NaOH $\frac{N}{10}$ per 100 cc. cream serum.	Method of acidifying.	Fat. (per cent.)
A	78	29.1	Addition of	28
	158	40	pure lactic	—
	180	44.4	culture	—
B	220	31.3		52
	510	33.3		—
	1080	37.5		—

Cream from new milk previously heated to 105° C for 20 minutes, and cooled rapidly.

C	70	21.7	Addition	31
	70	37.7	of lactic	—
	70	40.6	culture	—
	240	46.4		—
	1080	60.9		—
D	146	22	Addition	43
	200	54	of lactic	—
	220	64	acid	—
	270	66		—
	860	72.		—
E	127	23	lactic acid	40
	129	45.8		—
	141	56.6		—
	3600	73.		—



Acidity in cc. N/10 NaOH per 100 cc. cream serum.

Fig. IV.

As a matter of interest it may be mentioned that the increase of viscosity due to increased acidity imparts to the cream certain definite properties, viz. :—

(1) The property of whipping, and

(2) The property of buttering.

A cream of sufficient acidity (approaching the critical acidity) will readily whip, and having reached this condition, will, with very little further mechanical agitation, form butter. It is probable, therefore, that the butter-maker, in allowing the cream to ripen, not only aims at improving the flavour of the butter, but also takes advantage of this property of the cream acquired by acidification in order that the fat globules may coalesce with the minimum of loss. In making butter from fresh cream, a considerable loss of fat is inevitable, since the globules in this case have not the strong tendency to coalesce.

The probable explanation of the critical acidity is that at this point a definite change occurs in the proteins of the cream serum, and the nature of this change is such that the protein, which forms a kind of envelope around the fat globules, impedes their free motion in rolling past one another.

This theory is supported by the fact that in separated milk there is no such sharp rise in viscosity on acidifying as is the case with cream, although at the degree of acidity of the milk which corresponds to the critical acidity of the cream serum there is a definite change in the proteins present, evidenced by a visible precipitation.

The capillary of the viscosimeter employed for the experiments with separated milk had only 1/3 of the cross-section of the capillary used for the cream, so that there is no reason to suppose that a relatively larger space was occupied by the milk in any part of the tube, than by the cream serum, which might otherwise be thought a possible explanation of the difference in behaviour of the two liquids.

In Nature of June 1st, 1911, there appeared a short summary of a paper on "Viscosity of Emulsions," by Baucelin, in which the following statement occurred :—"In accordance with the Einstein theory, increase of viscosity is found to be independent of the size of particles in suspension, and depends only on the total volume of particles per unit volume."

On this assumption, since the total volume of the fat globules in any cross-section of the capillary of the viscosimeter could not be supposed to occupy nearly 2/3 of the total space for any of the samples of cream employed, it is reasonable to assume that any increase in the viscosity of separated milk corresponding to that at the critical acidity of cream serum could have been detected by the use of the smaller capillary, and as no such rise is discernible, the critical acidity must be due to the change in the nature of the envelopes of the fat globules, and not to the addition to the liquid of solid matter in the form of precipitate.

Influence of Temperature on Cream Viscosity.

The effect of rise of temperature of the cream is, as one would naturally expect from the case of other fluids, to diminish the viscosity, at first rapidly, but after reaching a temperature of about 35 deg. C., the decrease in viscosity due to a further increase in temperature is less marked. At about this temperature the fat commences to melt, and the globules tend to coalesce, so that the nature of the liquid is changed, and the results of further rise of temperature are no longer comparable with those obtained by experiment with liquids containing suspended particles which are not thus affected by change of temperature.

Fat Content as Affecting Viscosity.

For the investigation of the effect of the fat content of cream in determining its viscosity, a number of samples of cream, separated from the same milk, and differing only in fat content, were employed, the experiments being performed, as before, at a constant temperature of 25 deg. C., with an Ostwald viscosimeter.

The results of these experiments show that the viscosity of cream increases with increase in the fat conent, at first slowly, then more and more rapidly, till a viscosity is attained such that the cream will no longer flow.

In an interesting paper by Walter Hess, in Pflüger's Archiv. für Physiologie, May, 1911, on "Blutviskosität und Blutkörperchen," a new theory of the relation between viscosity and content of solid particles in blood was put forward. It is as follows:—Supposing a number of samples of blood, the plasma of which has the same viscosity for all, but which contain different quantities of solid particles, amounting to 10 per cent., 20 per cent., and 30 per cent., and so on for the different samples, the viscosity of any sample will be inversely proportional to the amount of plasma contained.

Hence the viscosities of the various samples will be 100/90, 100/80, 100/70, etc., of the viscosity of the plasma, and hence the viscosity of a sample containing 10 per cent. of solid particles will be 8/9 of that containing 20 per cent., so that a sample containing 50 per cent. solid particles would have a viscosity twice as great as that of the plasma.

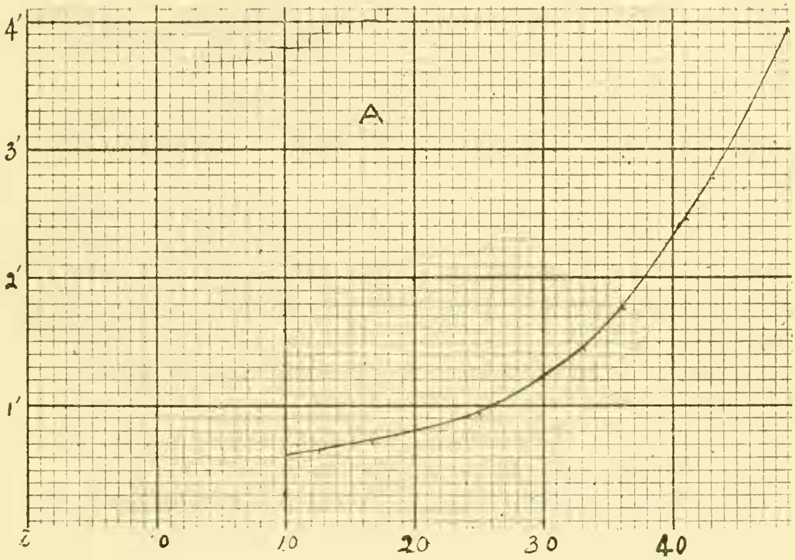
An attempt was made to apply this theory to the viscosity of cream, but it did not even approximately agree with the results of the experiments for the viscosity of samples of cream of varying fat content, since the viscosity of a sample of 50 per cent. fat is found to be nearly twelve times as great as that of separated milk.

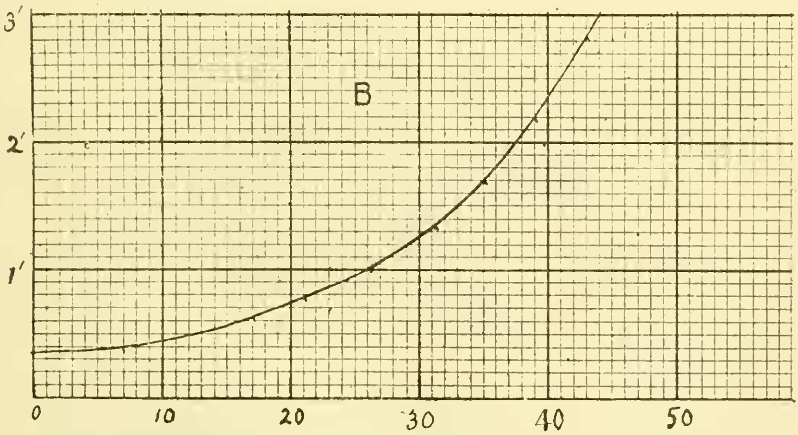
From the actual experimental results it would appear that at constant temperature the viscosity is a quadratic function of the fat content, and the relation between these two quantities may be graphically represented by a hyperbola.

TABLE V.

Cream from new milk.

	Time of flow (seconds)	Fat content (per cent.)
Experiment A	57	25
	89	33
	103	36
	146	41
	168	43
	240	49
Experiment B	20.8	—
	38	17.2
	47.4	21.06
	61	26.1
	80	31.2
	102	31.1
	132	39
	169	44





Fat Content.

Fig. V.

SUMMARY.

1. The main factors instrumental in varying the viscosity of cream are acidity, temperature and fat content, and of these three the first holds the most important place.

2. Increase in acidity produces very little effect on viscosity of cream, up to the "critical point," at which a sudden sharp rise in viscosity occurs.

3. The change in viscosity of separated milk at the degree of acidity corresponding to the "critical acidity" of cream is very slight—i.e., for separated milk there is no "critical acidity," proving that this is a property of the fat globule, or rather of its envelope.

4. Increase in temperature of cream diminishes its viscosity, at first rapidly, afterwards at a slower rate.

5. The viscosity of cream is a quadratic function of the fat content, if the other factors remain constant.

In conclusion, I take this opportunity of expressing my sincere thanks to Dr. Rothera, at whose suggestion this work was undertaken, for his continued interest and help.